



NRL -- FNMOC

Data Assimilation Efforts Related to JCSDA



A Briefing Presented to

JCSDA

Science Steering Committee

30 May, 2007

By

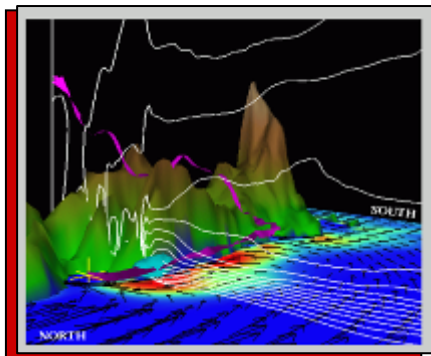
Patricia A. Phoebus

Associate Superintendent
NRL Marine Meteorology Division



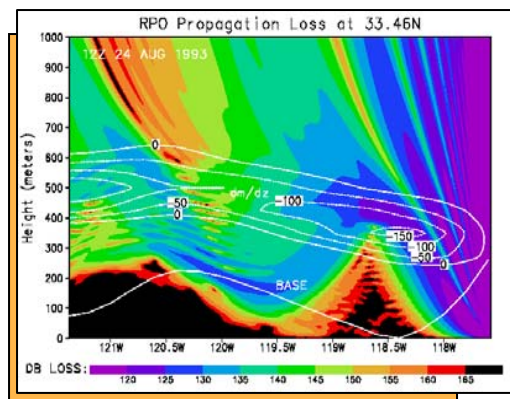
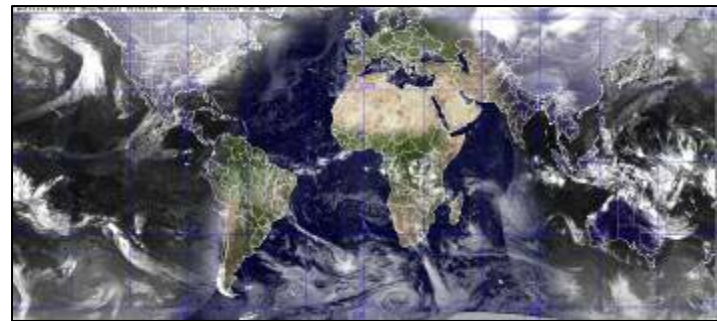
MARINE METEOROLOGY DIVISION

MISSION



To understand and simulate the behavior of the lower atmosphere on local, regional, and global scales, including its interaction with the ocean, land, cryosphere, and middle atmosphere.

To apply new scientific knowledge to the development and implementation of objective analysis and prediction systems for the Navy and other DoD users.



To integrate and automate weather interpretation systems for Navy and other DoD operations, including the effect of atmospheric conditions on weapons systems.

...Meeting identified and *anticipated* DOD needs.



MARINE METEOROLOGY DIVISION

Organization and Staff



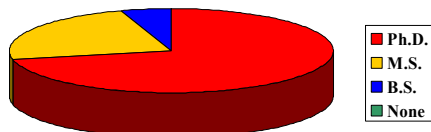
FEDERAL STAFF

1 SES

59 S&E professionals

10 Support Staff

1 Active Duty Military

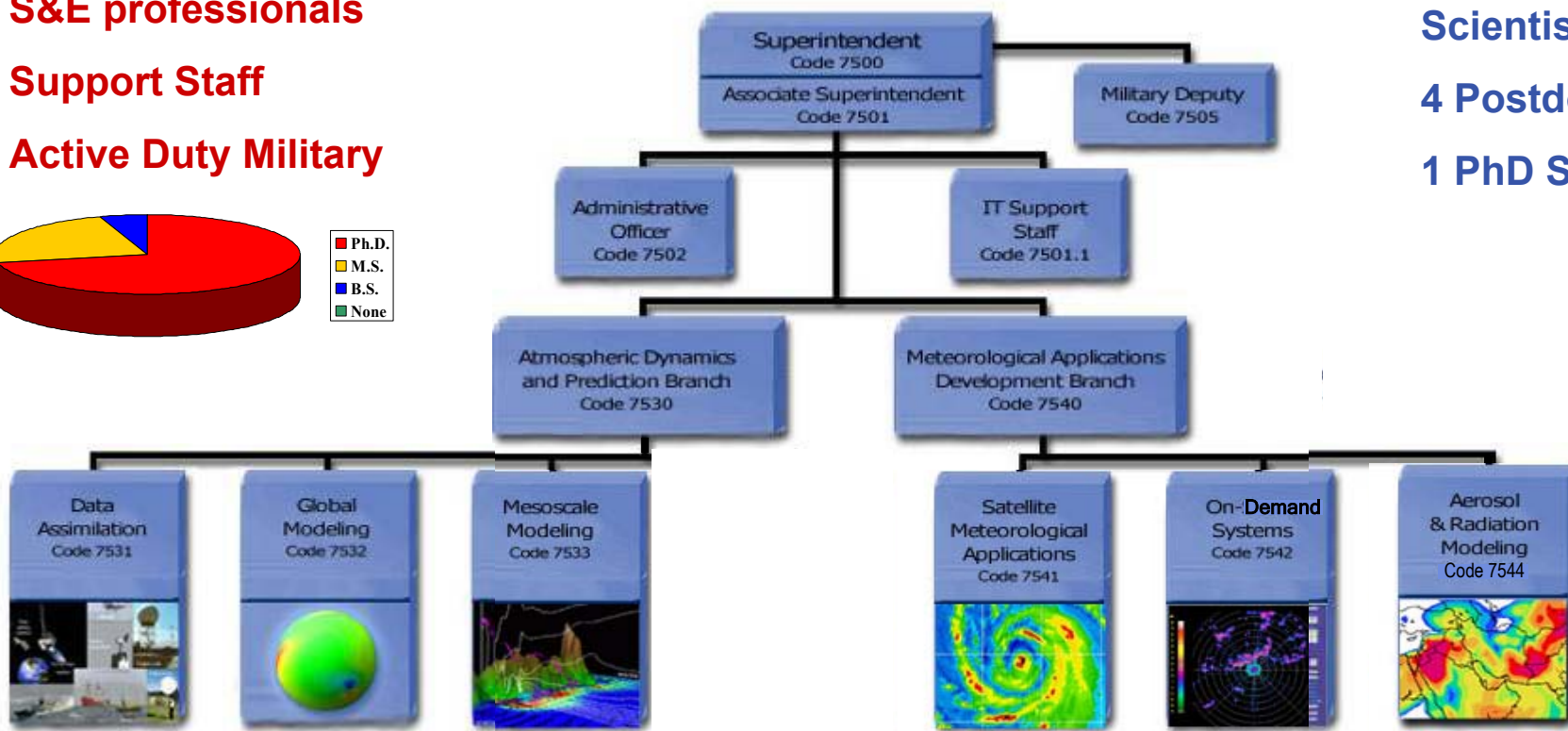


LONG-TERM VISITORS

5 Visiting Scientists

4 Postdocs

1 PhD Student



ON-SITE CONTRACTORS: 7 Research; 7 IT Support; 1 Admin

~100 Total Staff
On-site

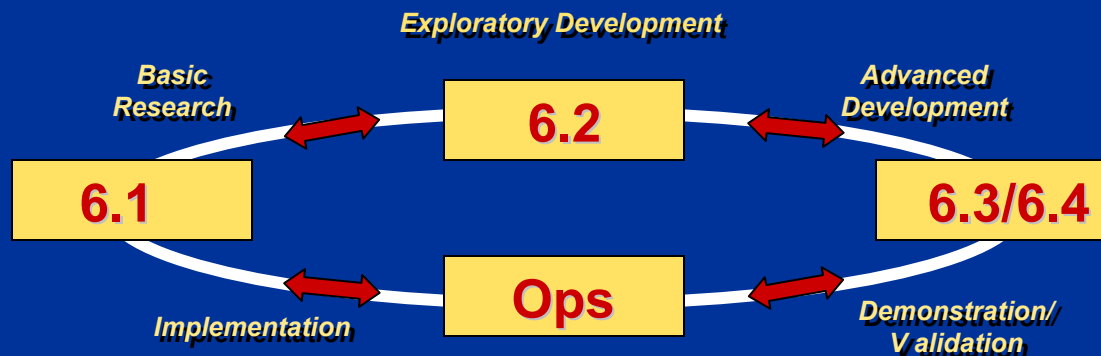


MARINE METEOROLOGY DIVISION

Unique Program and Partnership



Special Partnership with Primary Customer FNMOC



- ✱ **Seamless transition from research to operations.**
- ✱ **Operational problems can be quickly addressed by NRL.**
- ✱ **Complex operational systems are used in basic research.**
- ✱ **Operational requirements can influence basic research.**

Navy Meteorology Program is Unique—No “Valley of Death”.



NRL -- FNMOC

Personnel Contributions to JCSDA



- ✳ **Dr. Simon Chang, Management Oversight Board**
- ✳ **Ms. Patricia Phoebus, Deputy Director**
- ✳ **Dr. Craig Bishop, Head, Science Steering Committee**
- ✳ **Dr. Nancy Baker, Technical Liaison**

Contributing Scientists

Data Assimilation Section ---Dr. Nancy Baker, Dr. Craig Bishop, Dr. Clay Blankenship, Dr. Bill Campbell, Dr. Jim Goerss, Dr. Pat Pauley, Dr. Ben Ruston, Dr. Keith Sashegyi, Dr. Liang Xu, Mr. Steve Swadley (METOC Consulting), Dr. Tom Rosmond (SAIC)

Global Modeling Section ---Dr. Tim Hogan, Dr. Rolf Langland, Dr. Jim Hansen

Aerosol and Radiation Section ---Dr. Douglas Westphal, Dr. Jeff Reid, Dr. Xialang Zhang

Satellite Applications Section ---Mr. Jeff Hawkins

Oceanography Division ---Dr. Jim Cummings

Space Sciences, Remote Sensing Divisions (NRL DC) ---Dr. Gerald Nedoluha, Dr. John McCormack

FNMOC --- Dr. Randy Pauley, Dr. Jeff Lerner, Mr. Mark Ignazewski



- Implementing JCSDA **Community Radiative Transfer Model** for all satellite radiance assimilation
 - JCSDA Community Radiative Transfer Model (CRTM) has been implemented for the AQUA sensors
 - also implemented for AMSU/A, SSMIS, and AIRS assimilation systems
- CRTM for Zeeman splitting
- Using JCSDA code to read satellite radiances
- AIRS 328 channel subset



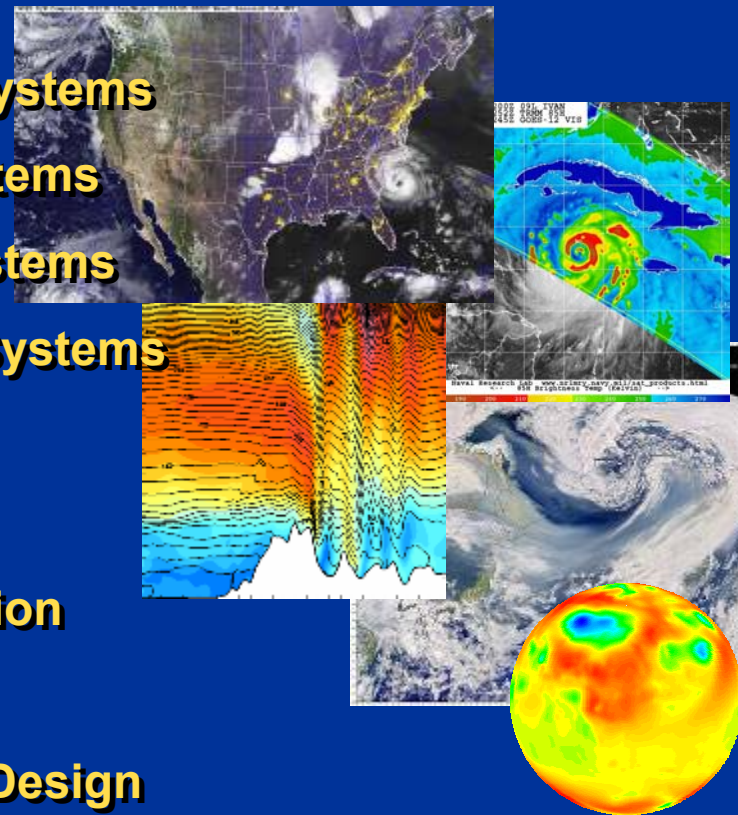
MARINE METEOROLOGY DIVISION

Applied Research Focus



NRL MRY is a \$20 Million National Asset

- ✱ **Multiscale Data Assimilation/NWP Systems**
- ✱ **Multiscale Ensemble Prediction Systems**
- ✱ **Aerosol Analysis and Prediction Systems**
- ✱ **Coupled Environmental Prediction Systems**
- ✱ **Multi-sensor Satellite Data Products**
- ✱ **Nowcasting of Tactical Parameters**
- ✱ **Tropical Cyclone Analysis & Prediction**
- ✱ **Software Design for HPC Systems**
- ✱ **Automated, Interactive, Web-based Design**



DOD's Only Laboratory S&T Program in NWP

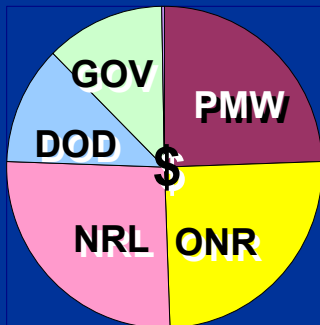


MARINE METEOROLOGY DIVISION

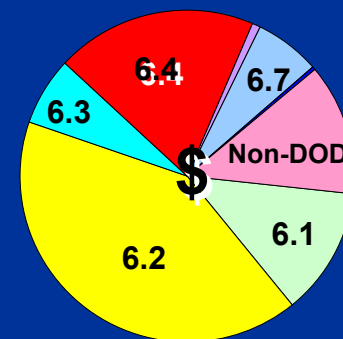
Leveraging Multiple Funding Sources



NRL MRY is a \$20M National Asset



Projects of interest to JCSDA at NRL are funded by various sponsors, including the NRL Base Program, ONR, PMW-180, and other DOD and Government agencies.....including JCSDA.



- ✱ **Base program funds basic research in advanced DA methods, predictability, ensembles; development of operational systems**
- ✱ **ONR funds research and development in aerosol DA and 4DVAR.**
- ✱ **PMW-180 funds implementation of upgrades to operational systems, including adding new satellite instruments.**

NRL MRY Competes for 100% of our Funding



NAVAL RESEARCH LAB

Data Assimilation Efforts Funded by JCSDA



- ✦ Detection and Correction of Aerosol Contamination in Infrared Satellite Sea Surface Temperature Retrievals (FY03—FY05)
- ✦ SSMI/S Brightness Temperature Evaluation in a Data Assimilation Context (FY04—FY06)
- ✦ Assimilation of Passive Microwave Radiance over Land: Use of the JCSDA Common Microwave Emissivity Model in Complex Terrain Regions (FY04-FY06)
- ✦ Improved Photochemical Parameterizations of Stratospheric O3 and H2O for NWP Systems (FY05-FY06)
- ✦ Development of Global Near-Real-Time Aerosol Optical Depth Analysis for Use in Aerosol Transport Models (FY05-FY07)
- ✦ Satellite Channel Selection with the Data Assimilation Adjoint (FY05-FY07)

The NPOESS IPO contributes \$500k annually to JCSDA on behalf of DOD. Computational time and data storage resources to support these projects was contributed primarily by FNMOC and NRL, with the balance from HPC.



NAVAL RESEARCH LAB

Data Assimilation Related Research



NRL conducts basic research in predictability, data assimilation methodologies, ensembles, and adjoint applications that have contributed new and innovative science and technology that is being applied by NRL and other JCSDA partners toward improved capabilities for satellite data assimilation.

Multidimensional Data Assimilation Methodologies

- ✳ **Cycling Accelerated Representer method for fast and efficient solution of first operationally feasible *weak-constraint 4DVAR*.**
- ✳ **First *adjoint* of a *data assimilation* system.**

Quantifying the Limits of Atmospheric Predictability

- ✳ **Application of the data assimilation system adjoint to development of tools for assessing *impact of observations* on forecast error.**
- ✳ **Use of adjoint tools to *select, thin, QC, or target* remotely sensed data.**
- ✳ **Demonstrated the need for *flow-dependent error covariances* to maximize impact of additional observations.**



Advanced Data Assimilation

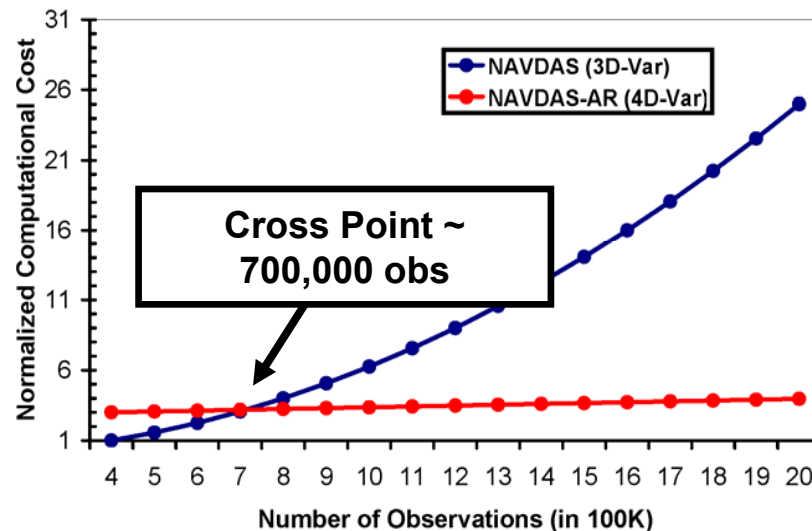
NAVDAS-AR (4DVAR)



NRL has developed the first operationally feasible weak constraint 4-dimensional variational atmospheric data assimilation system.

PAYOFF: NAVDAS-AR provides optimum solution for efficiently exploiting volumes of new and unconventional data types (aerosol, cloud, soil moisture, stratospheric chemical species, etc.) for battlespace characterization and model initialization in the upcoming NPP/NPOESS era.

Computational Cost of NAVDAS vs. NAVDAS-AR



TRANSITION PLAN:

NAVDAS-AR prototype running at FNMOC with radiance assimilation.

Initial skill and computational speed meeting or exceeding expectations.

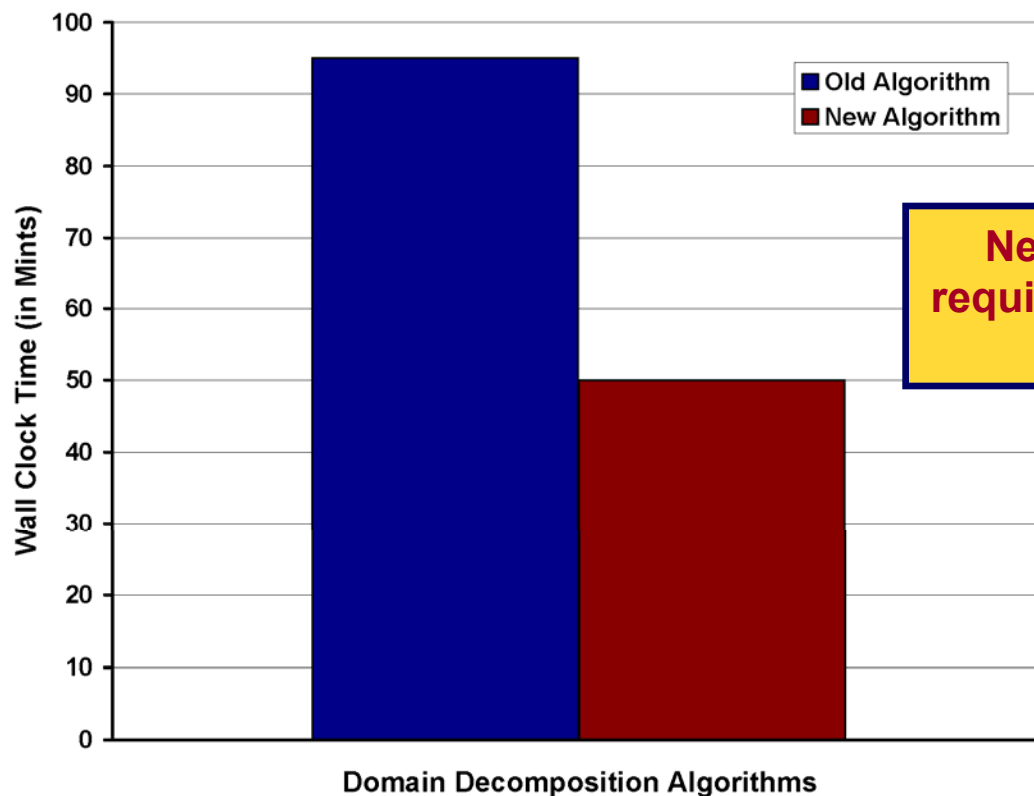
RTP funding for FY08 transition into NOGAPS available; work on schedule.

Beginning to merge with ocean data assimilation system, NCODA.

JCSDA interested in NAVDAS-AR methodologies for research.



A New Domain Decomposition Algorithm for the “AR”



New domain decomposition algorithm requires about half of the computation time to achieve the same accuracy.

FY08 plans include a new conjugate gradient solver, which should further increase the computational efficiency. The code will also be ported to the FNMOC A2 LINUX Cluster for increased throughput.



NAVDAS ADJOINT

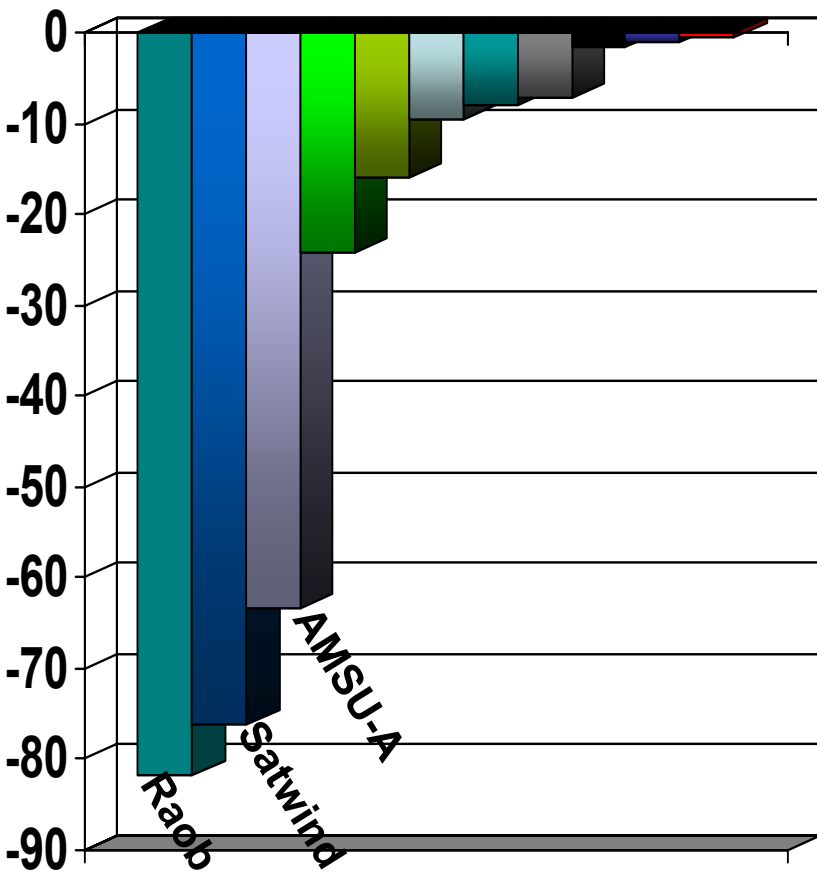


Total Impact by Observation Type

Units of impact = J kg⁻¹

1 Jan – 28 Feb 2006
00UTC Analysis

Beneficial
impact



- Raob
- Satwind
- AMSU-A
- Aircraft
- Scatwind
- Ship
- Modis
- Land
- Ausn
- Dropsonde
- TC Bogus



NAVDAS ADJOINT



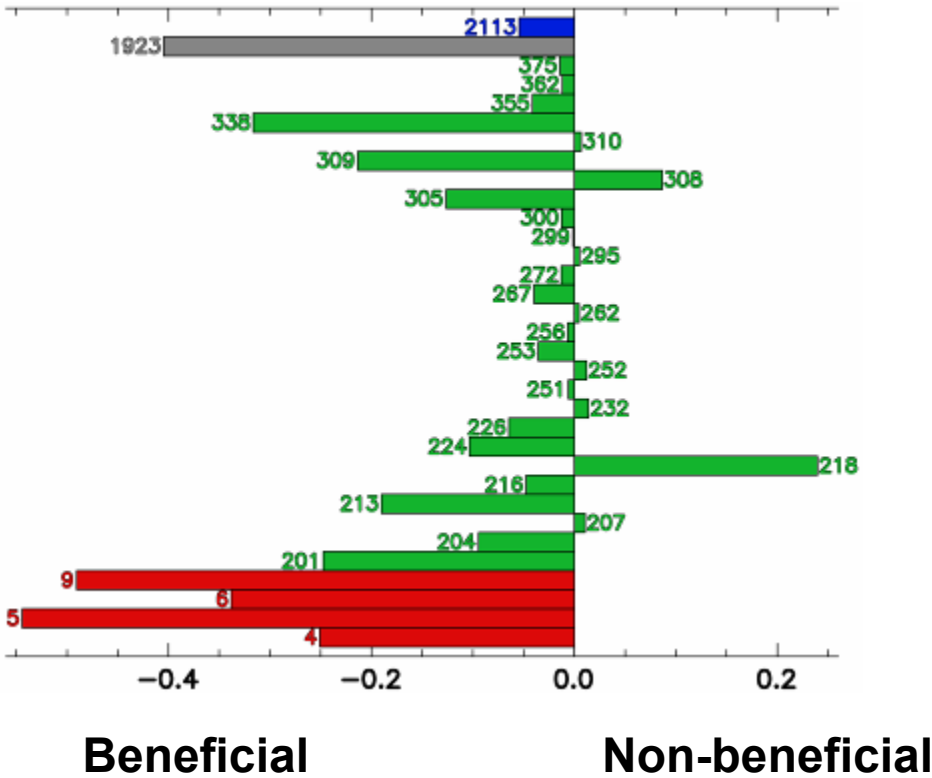
Total Impact by Satellite Channel

Assessment of AQUA sensors

AMSU/A, AIRS longwave 14-13 μ m,
AIRS shortwave 4.474 μ m, AIRS shortwave 4.180 μ m

• AIRS has 2378 spectral channels!

AQUA sensitivity specified by channel number: Aug 15-26, 2006



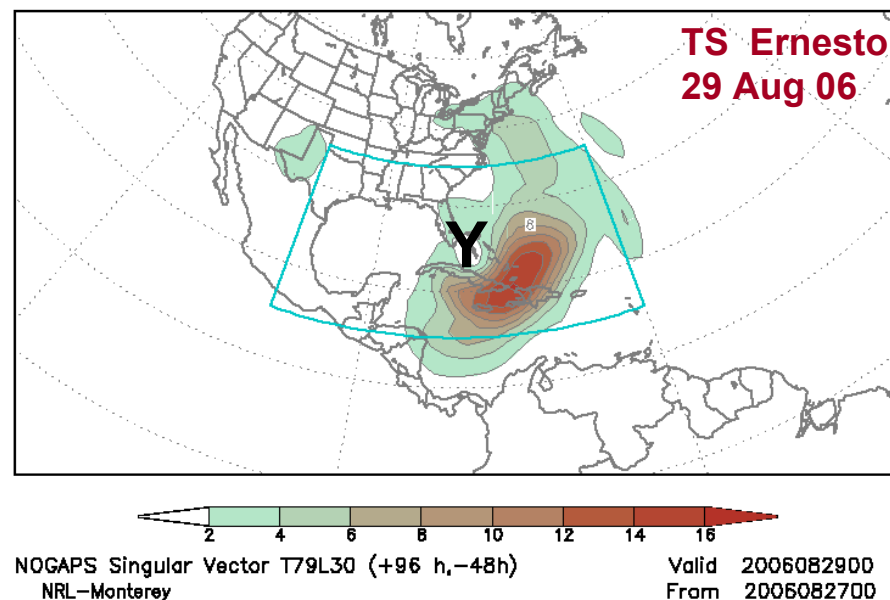
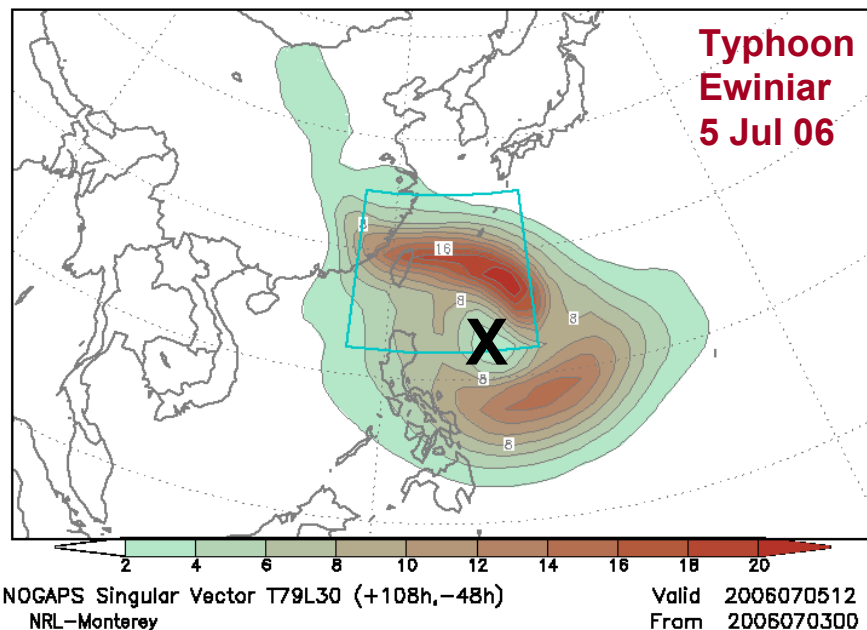
- NRL pioneered methodology for quantifying reduction in forecast error for each individual satellite channel
- JCSDA partners will use methodology to optimally select satellite observations for maximum NWP impact.
- Comparison of observation impact results between JSDCA partners will help identify problems with observing systems and assimilation systems.

Funded in part by JCSDA



Targeted Observation Research & Products

Sensitivity of the storm forecasts to changes in the initial state (target regions)



NRL real-time targeted observing products demonstrate where extra satellite observations could be assimilated or extra dropsondes released to improve the forecasts of the storms.

A number of sensitivity and adaptive observing products are produced daily at FNMOC in demonstration mode or to support field programs.



NAVAL RESEARCH LAB

Satellite Data Assimilation Development



- A key function for the JCSDA partners is to **remove duplication of effort and distribute the workload** associated with preparing data from so many different sensors for assimilation into our modeling systems.
- Areas where JCSDA partners have expected **Navy to lead** are in the assimilation of WindSat, SSMI/S, and aerosol, and land surface emissivity.
- **Software and/or lessons learned** will be shared with other partners.

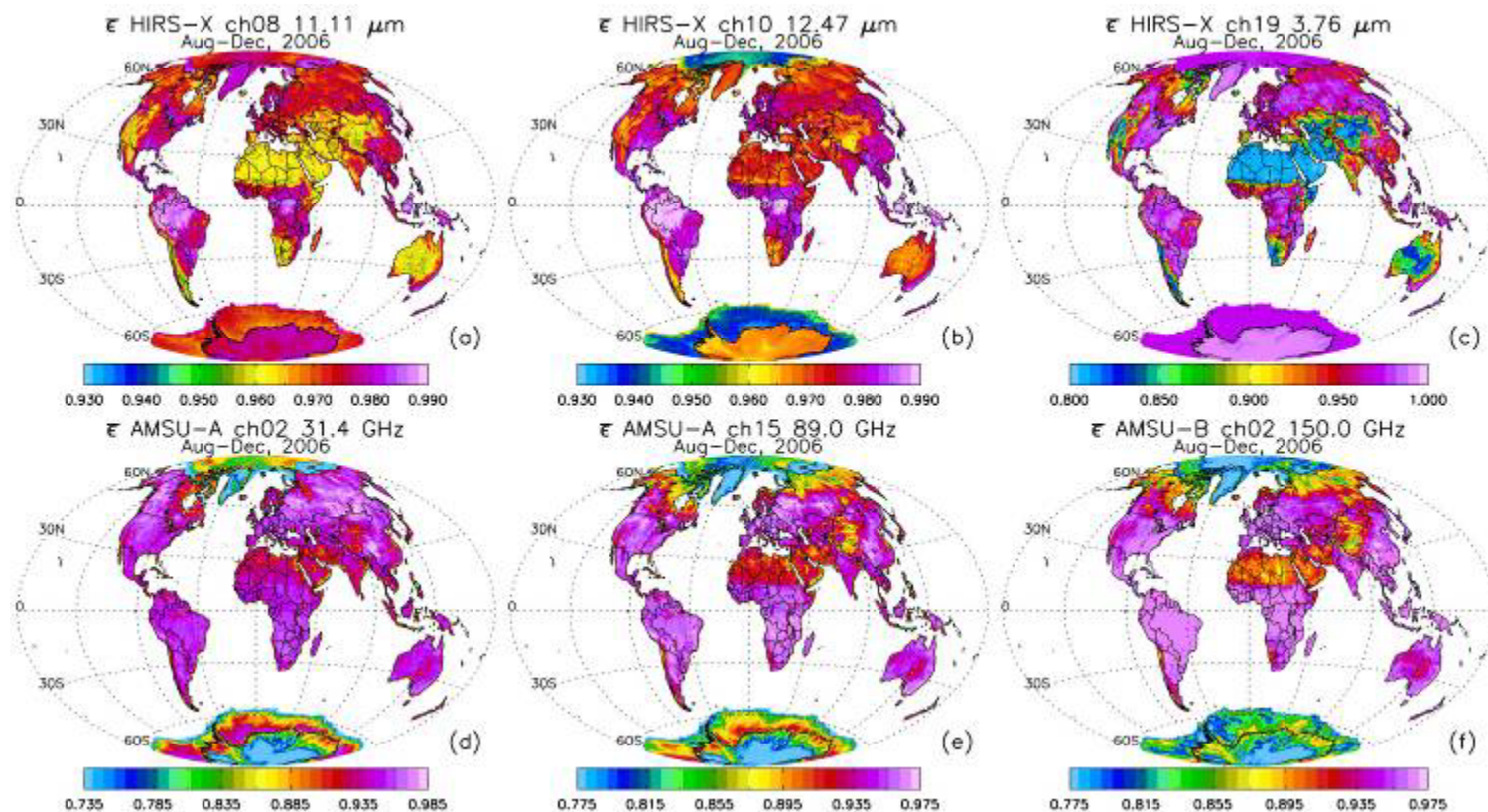


Land Surface Emissivity Retrieval

1DVAR Preprocessor (pre-operational)



- Use with radiances from ATOVS suite and AIRS/AMSU
- simultaneous adjustment of atmosphere and LST/emissivity
- methodology to incorporate surface sensitive radiances over land



Used to access Microwave Emissivity Model (MEM) included in JCSDA Community Radiative Transfer Model (CRTM)



Radiance Assimilation

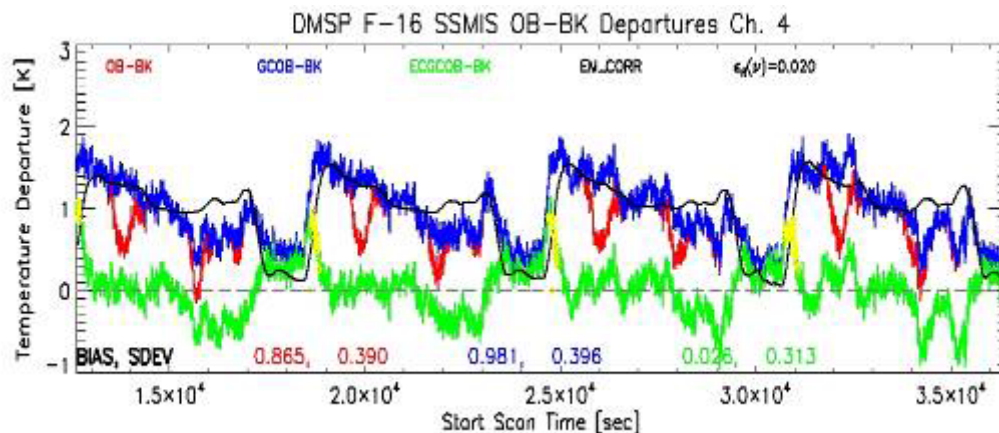
Unified SSMIS Radiance Preprocessor



- Significant SSMIS Calibration Anomalies uncovered during Cal/Val
- Calibration errors exceed accuracy thresholds for NWP ($\sim 0.25\text{K}$ for temperature sounding channels)
- Objective is to develop a **unified radiance preprocessor** for NWP/JCSDA users to correct for calibration anomalies
- Implementation of unified SSMIS Preprocessor at FNMOC for F-16 planned for late summer 2007
- Data will be distributed via Shared Processing Network

NRL Collaborations

- **SSMIS Cal/Val Team** – Determined physical mechanisms responsible for SSMIS Calibration Anomalies
- **Met Office** – SSMIS BUFR Based Preprocessor
- **JCSDA** – Discussions about alternative NESDIS preprocessor algorithms
- **ECMWF** – Provides Analyses of T(p) to 0.01 hPa ~ 80 km





Radiance Assimilation

SSMIS Upper Atmosphere Capabilities



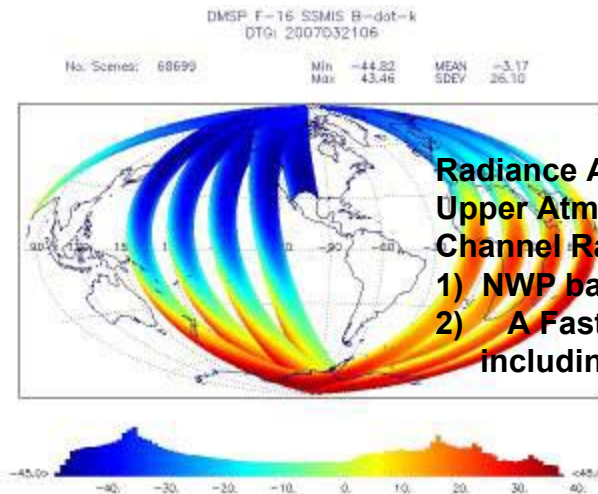
Middle Atmosphere (40 – 80 km) Data Assimilation

Motivations

- Extend NWP predictability
- Analyze and Forecast Stratospheric O₃ and related constituents and their role in Weather and Climate
- Provide correlative measurements for new satellite systems
- DoD Specific Interests – high altitude vehicles, communications, missile defense, Intel
- SSMIS pre-processor will provide calibration anomaly corrected radiances

NRL Collaborations

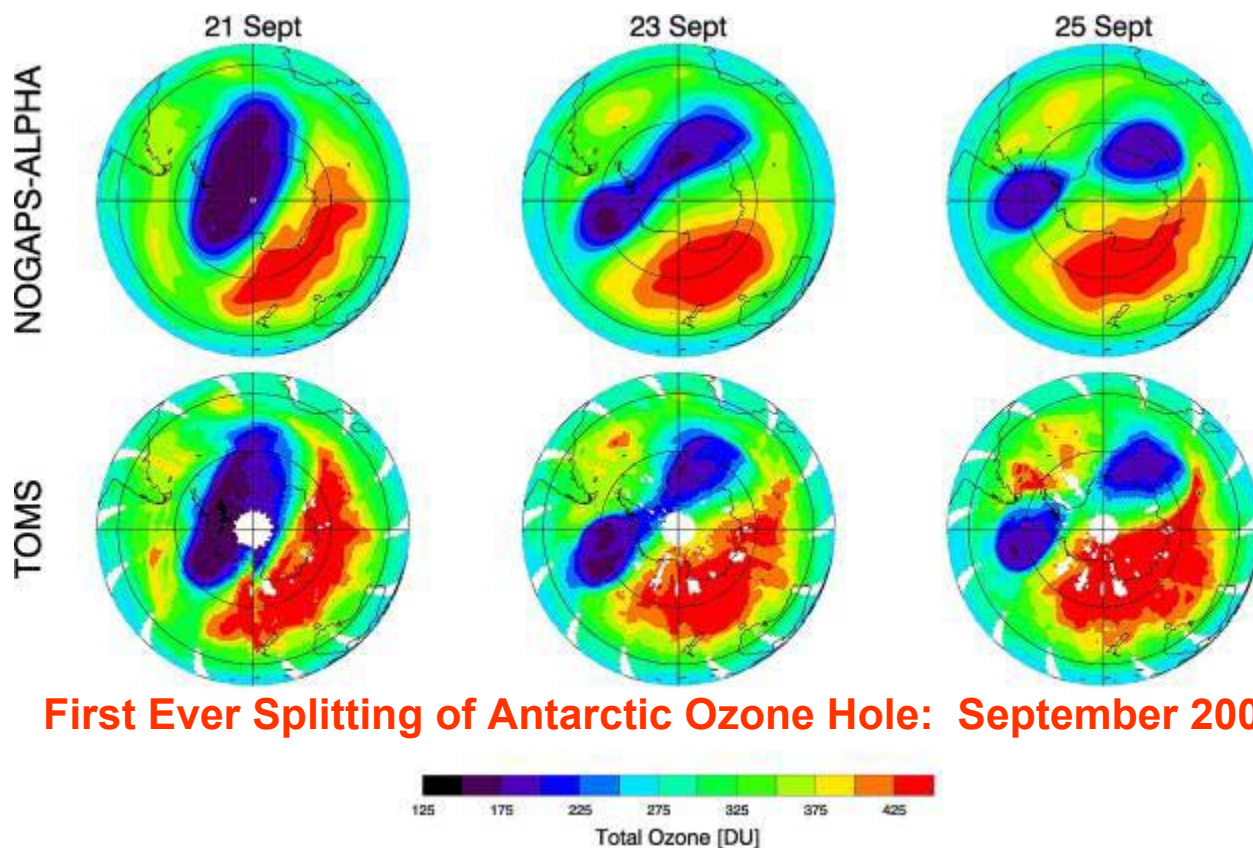
- **JCSDA** – Fast Upper Atmosphere Radiative Transfer Model with Zeeman Effects – CRTM-Z
- **ECMWF** – Provides Analyses of T(p) to 0.01 hPa ~ 80 km
- **Met Office** – SSMIS Anomaly Mitigation efforts
- **NASA JPL** – Lidar Temperature Profiles for verification





NOGAPS-ALPHA

Homogeneous Ozone Photochemistry Scheme



NRL Space Science Division

“NOGAPS-ALPHA provides a state-of-the-art stratosphere for NWP applications”

“We get a much improved split vortex in the +5 day forecast by using

- (a) new T239L54 NOGAPS-ALPHA
- (b) new 3DVAR-based reanalysis (NAVDAS)

First Ever Splitting of Antarctic Ozone Hole: September 2002

CHEM2D-OPP has to date proved superior to photochemistry schemes used in the ECMWF IFS, [former] NCEP GFS, & NASA GEOS5 & GISS models.

This work was funded by the JCSDA and was delivered to NCEP GFS and NASA GMAO as well as NOGAPS.



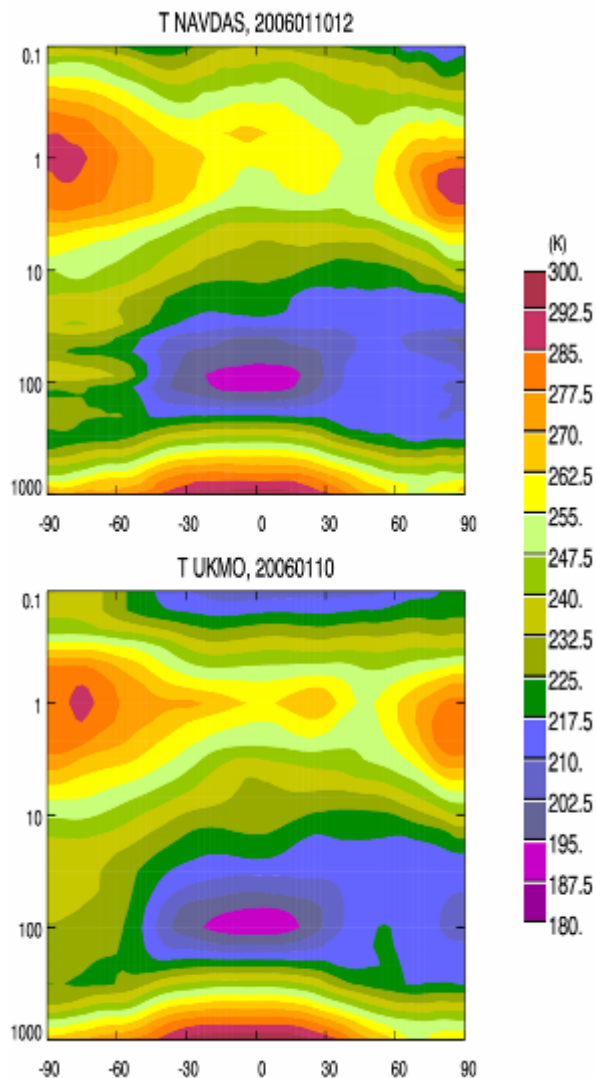


NOGAPS-ALPHA



Microwave Limb Sounder (MLS) Assimilation

NAVDAS and UKMO Zonal Mean Temperature
Jan 10, 2006, 12UT



- NAVDAS (analysis) top at 0.1 hPa
- Assimilated conventional observations
 - including radiosondes and pibals, satellite tropospheric and surface winds and total precipitable water, surface land and ship, aircraft winds
- NOAA AMSU-A, channels 4-10
- MLS temperature retrievals from 31.6 to 0.1 hPa.
- NOGAPS-ALPHA T79L60 (model top 0.005 hPa)
- Assimilation run began 20 Dec 2005;
- Analysis is for 10 Jan 2006 (30 days of assimilation)

UKMO: Met Office Stratospheric Assimilation
Data from the British Atmospheric Data Center

**Upper atmosphere version of NAVDAS with
NOGAPS-ALPHA is in good qualitative
agreement with the Met Office analysis.**



Aerosol Data Assimilation



Goal of program: Develop **world's first** operational aerosol optical depth (AOD) **data assimilation system** to aid in the forecast of air quality and visibility.

Benefit for JCSDA partners: **Error characteristics and QC techniques** for aerosols. Demonstration that model quality and observation quality are adequate for operational assimilation of aerosols. **Observation operators for AOD.**

Input: Terra and Aqua **MODIS level-2 AOD** after screening and empirical corrections.

Status: Development of an over-ocean level-3 DA-quality satellite dataset has been completed, and aerosol optical depth has been added to **NAVDAS**. 6 month test run shows **significant improvements in aerosol model forecasts**

To be completed in FY07: Begin **quasi-operational runs** at NRL. Complete assessment of MODIS data-collect-5 over-land product.

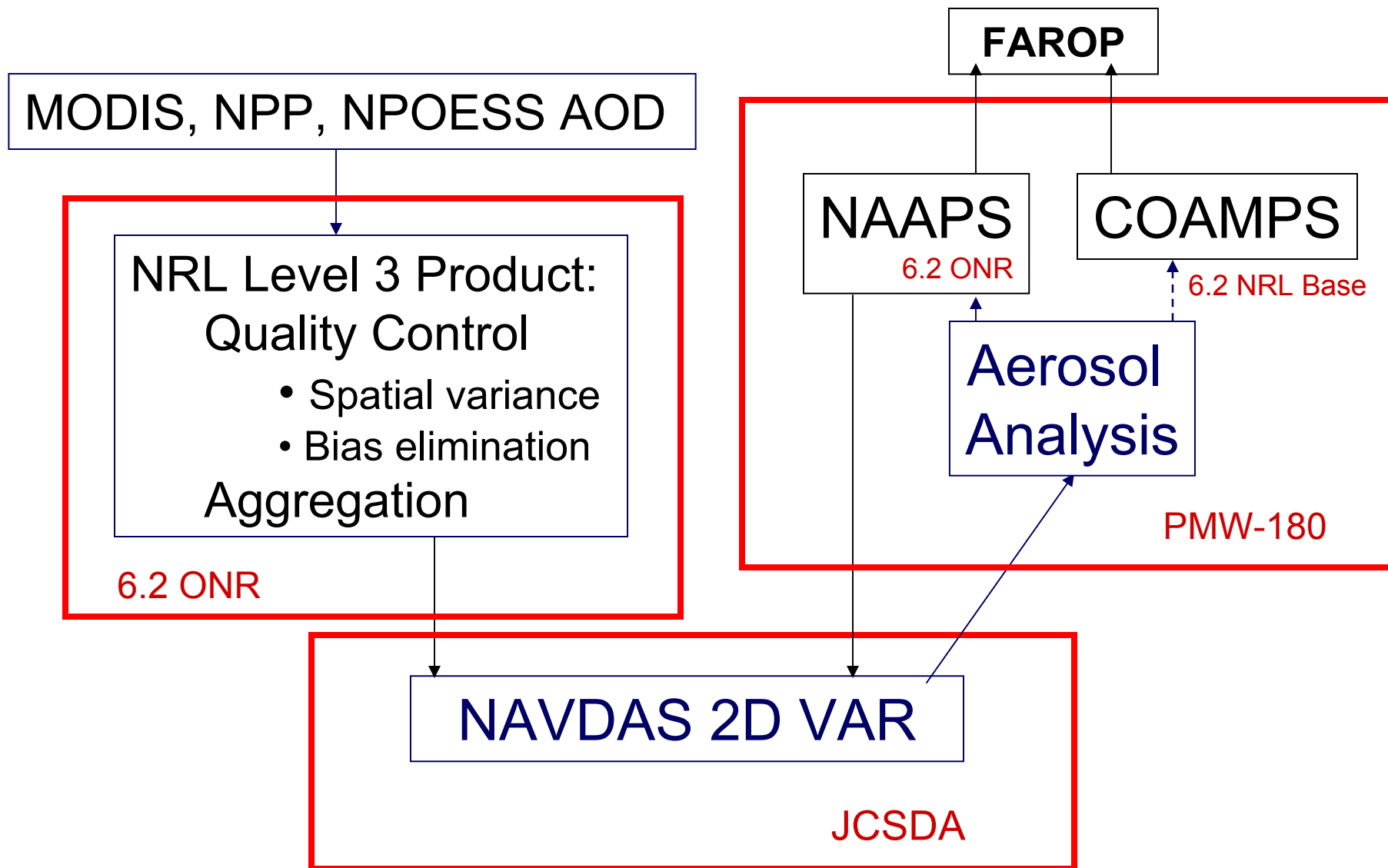
Future sensors: NPP/NPOESS, AVHRR, METOP, MSG, AATSR, GOES-R

Output:

| | |
|------------------------|---|
| Aerosol analysis: | 3-d distribution of four species (<i>dust, smoke, sulfate, salt</i>) |
| Horizontal resolution: | 1x1° (soon to be 0.5x0.5°) |
| Temporal resolution: | 6 hourly, forecasts to 144 hours |
| Distribution: | Internal, plots on web |



Aerosol Data Assimilation System





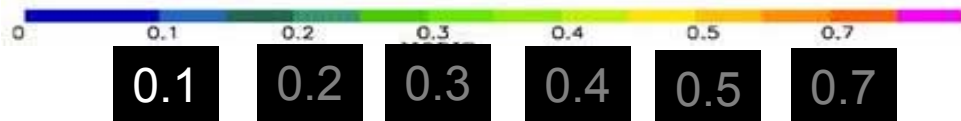
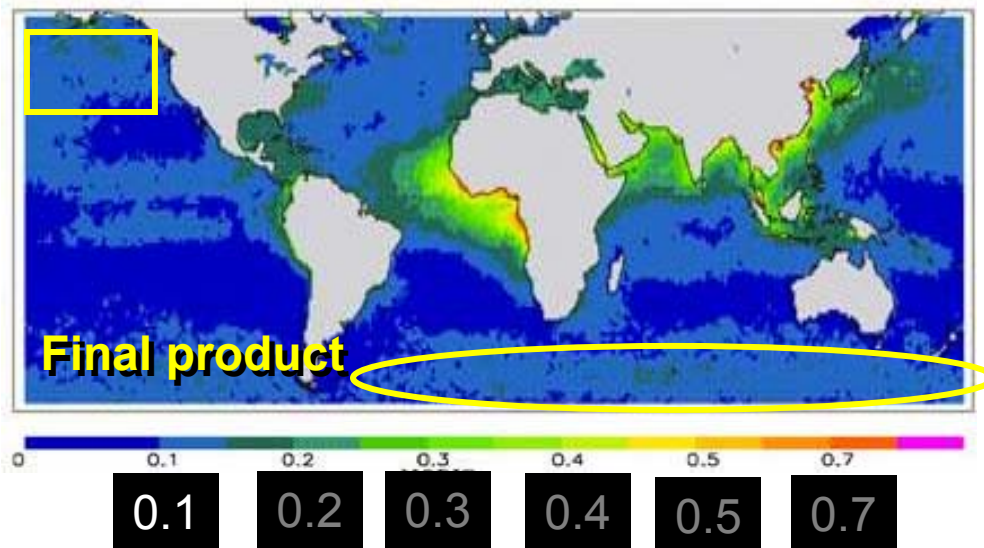
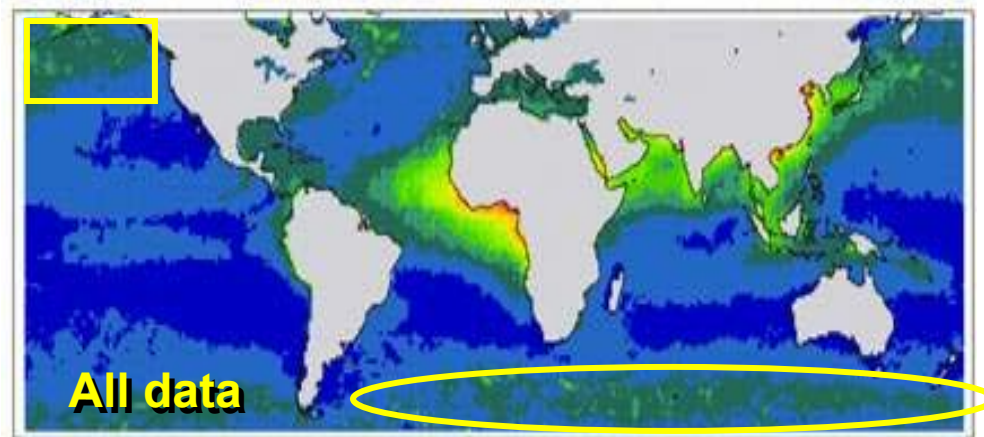
Aerosol Data Assimilation Program

Data Quality Control



Impact of QA and Aggregation on Level 3 Assimilated Data

- We begin with NRTPE MOD04 AOD data. Shown is 2004 annual average.
- QA: Data are screened using spatial tests and thresholds
- Empirical corrections are made based on satellite and NOGAPS environmental data.
- End result, up to 50% correction in southern oceans and Asian outflow to the north Pacific. 15-20% reduction in error globally.



MODIS Optical Depth



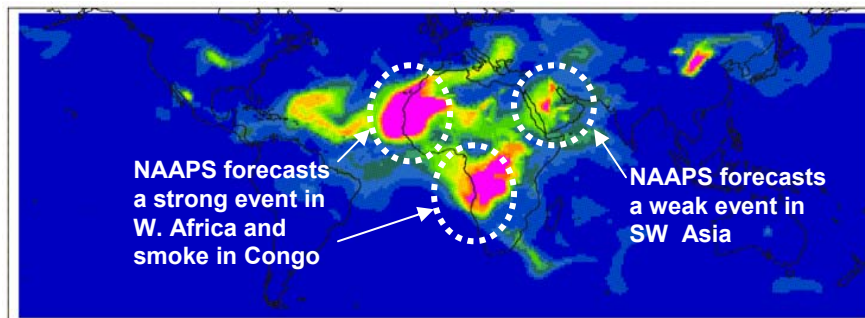
NAVDAS

Results for 12Z 19 July, 2005

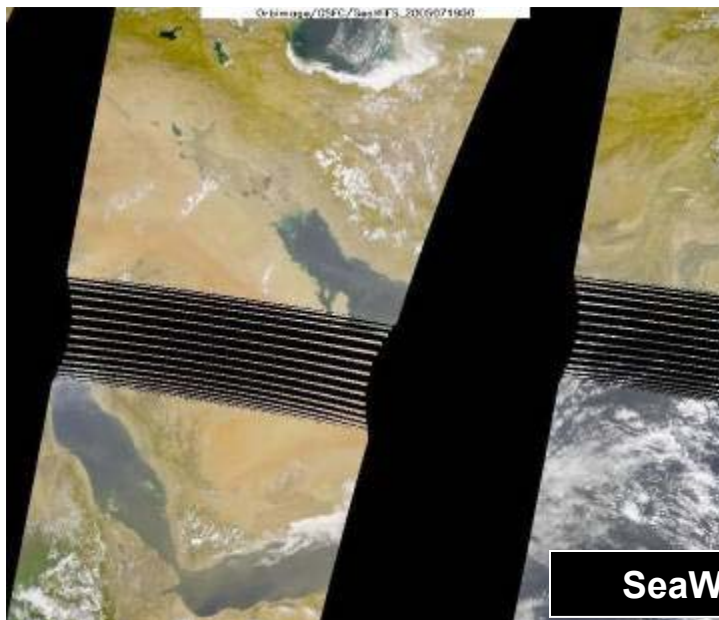
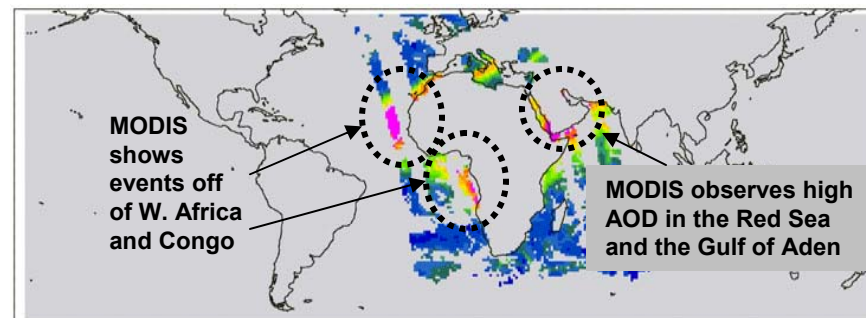


Assimilation of MODIS optical depth

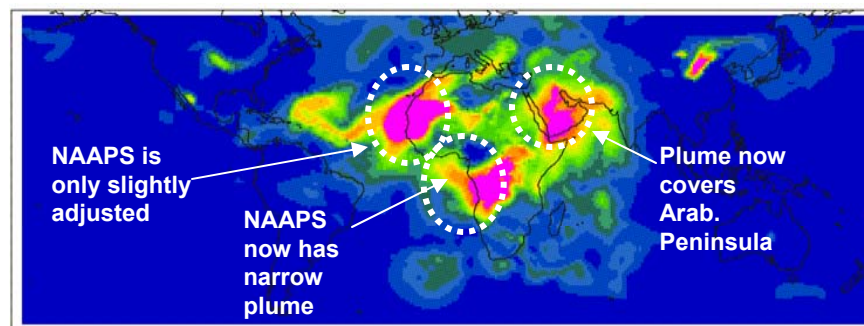
NAAPS first guess of AOD (12-h forecast) for 12Z, July 19, 2005



MODIS retrieved AOD for 09-15Z, July 19, 2005



NAAPS updated AOD analysis (NAVDAS innovation + first guess)



SeaWiFS Imagery shows widespread dust over SW Asia

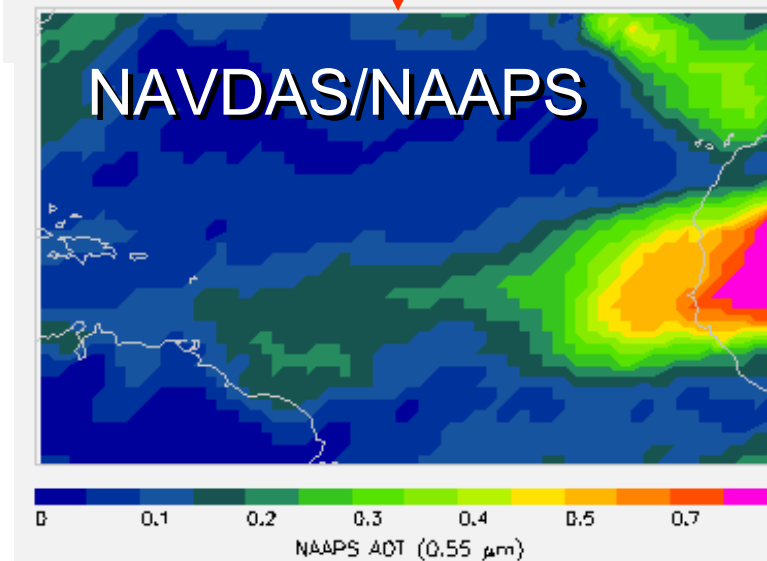
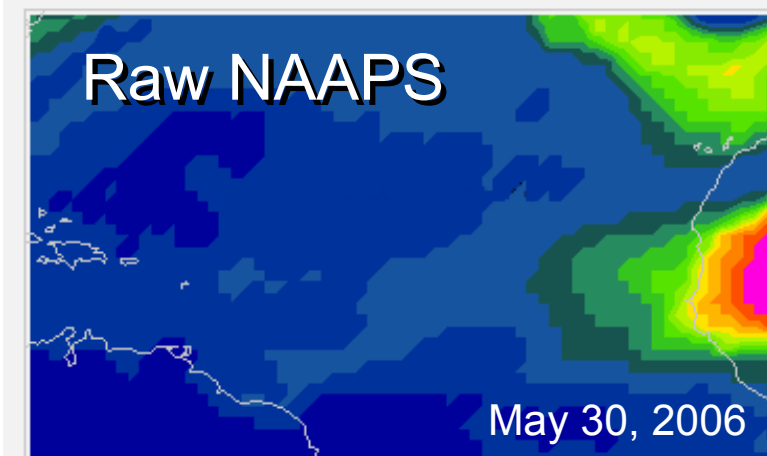
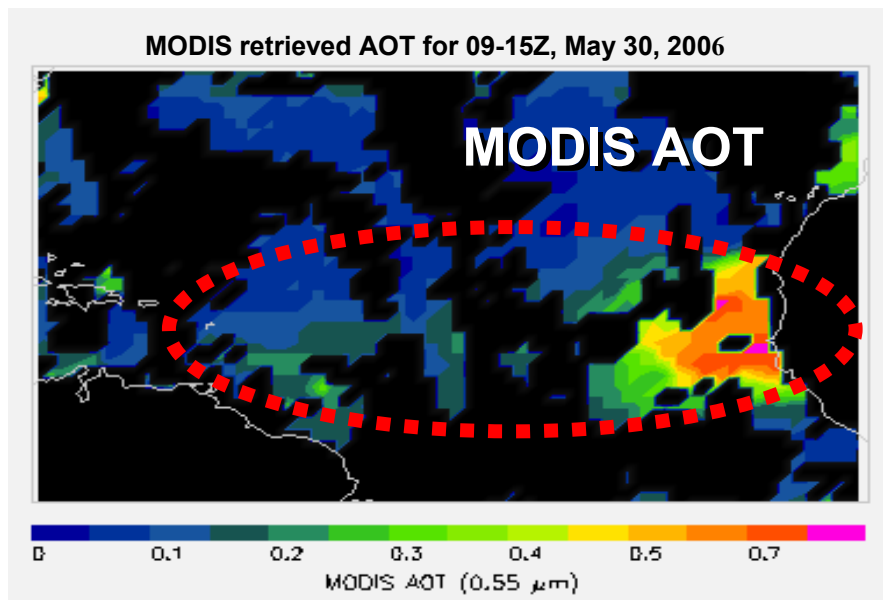


Prototype Aerosol Data Assimilation

Ready for 6.4



- **NAVDAS Aerosol completed.** Runs with Terra and Aqua MODIS level 2 data with **additional screening and corrections.**
- Significant effort spent on **background climatology** and **vertical placement.**
- **Five month evaluation.** NAAPS mean bias reduced by $>1/3$ for over 48 hours.





THE FUTURE OF NAAPS

Integrated into NOGAPS



Predictive tropospheric and stratospheric aerosol fully embedded within NOGAPS.

Fully interactive physics – aerosol, cloud formation, and radiative transfer.

Aerosol coupled to wave model; salt production from WW3.

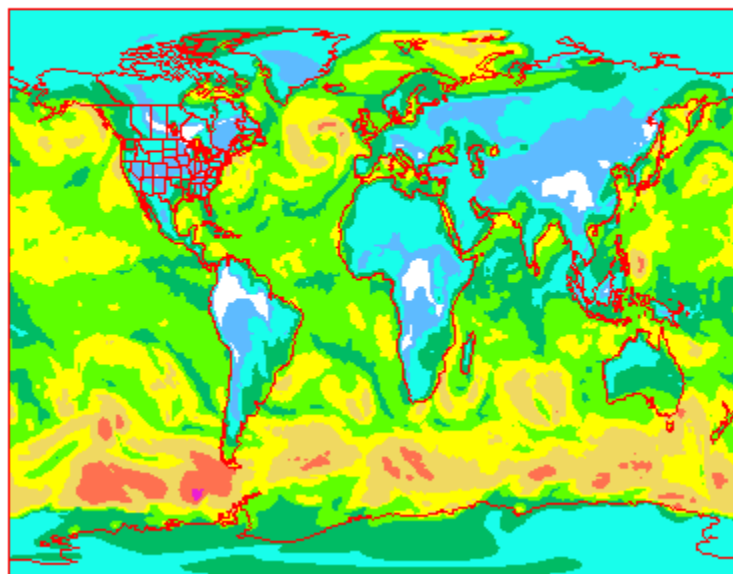
Aerosol data assimilation integrated into NAVDAS-AR.

Aerosol data assimilation will include UV and VIS radiances.

Aerosol impacts will be included in radiance data assimilation for NWP.

00:00Z 10 May 2006

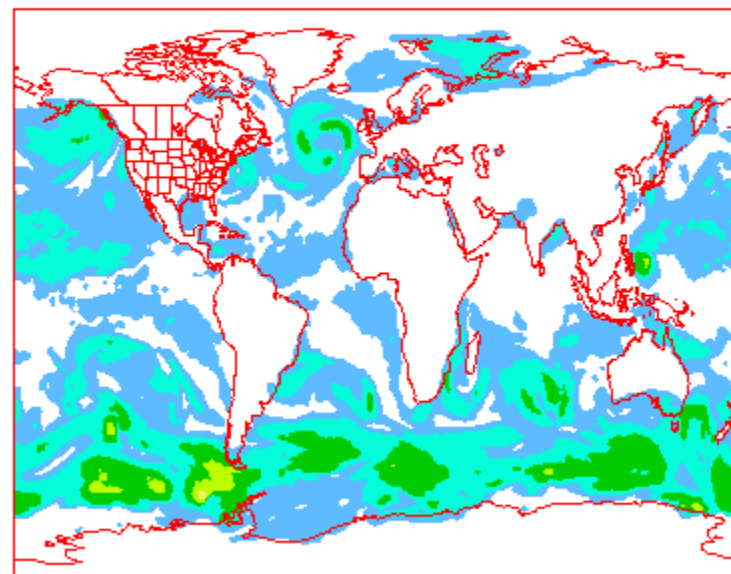
NAAPS Salt Mass Concentration ($\mu\text{g-m}^{-3}$)



0.1 0.3 1.0 3.0 10.0 30.0 100.0 300.0 1000.0

00:00Z 10 May 2006

NAAPS Salt Optical Depth



0.01 0.02 0.04 0.06 0.16 0.32 0.64 1.28



THE FUTURE OF NAAPS

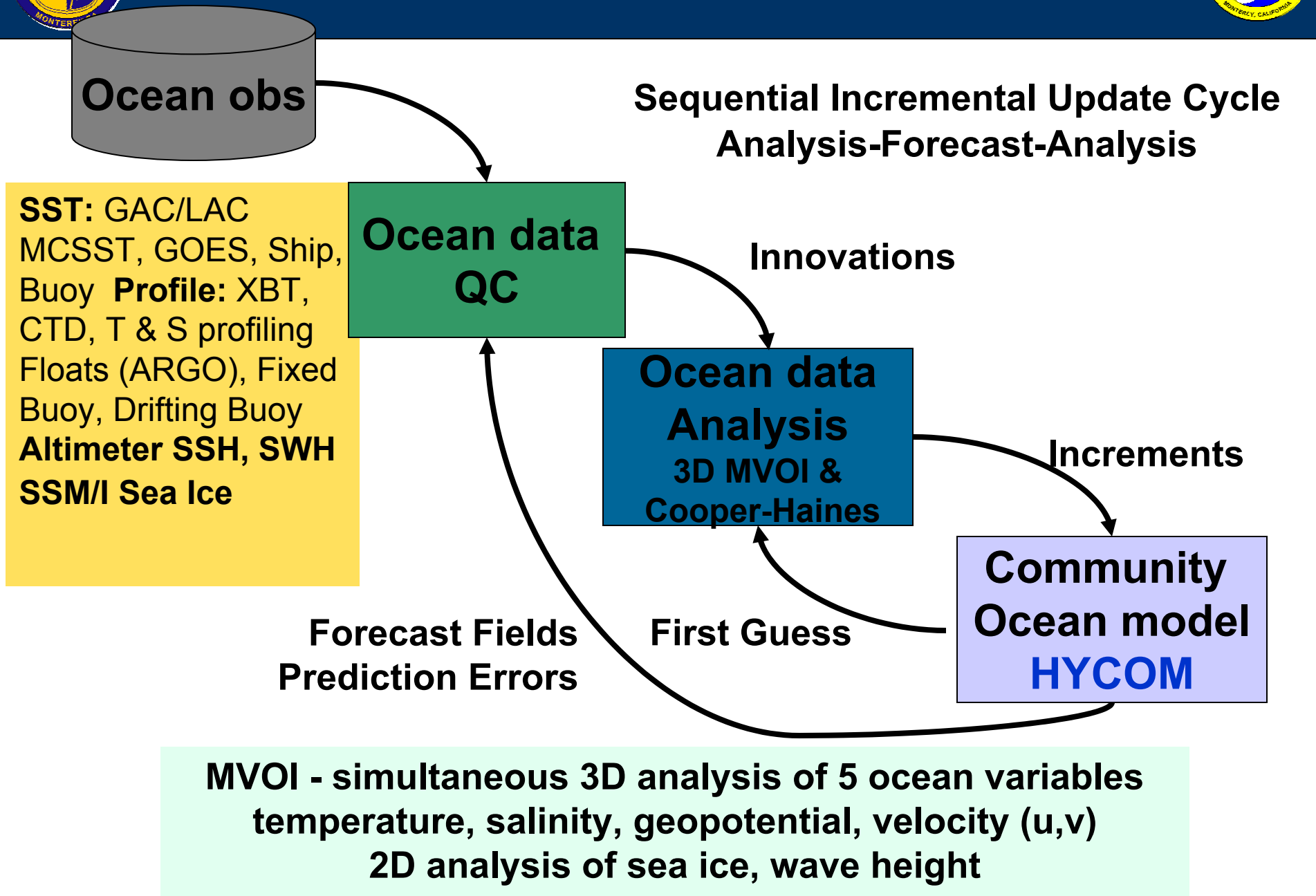
Integrated with Ocean Data Assimilation



- Aerosol dust causes **cold bias** in satellite SST retrievals.
- Dust contamination must be **detected and/or corrected**---JCSDA project between NRL, NAVO, and NESDIS.
- NRL developed a **canonical variate analysis** (CVA) procedure that uses NAAPS output, does the detection and returns the result as a probability of contamination.
- Probability useful to guide the **QC decision making** process in the ocean DA system (a fuzzy threshold test, already implemented in NCODA).
- Detection algorithm could be made part of the **SST retrieval process** at NAVO (to replace the gross screening algorithm now used).
- *Future plans are to **incorporate NAAPS wavelength fields** that match the channel wavelengths of the sensors used to generate the SST into the CVA algorithm (no funding in place to do this).*
- *Future plans are to **incorporate SST correction algorithm** in the retrieval process (if NESDIS delivers a working algorithm to JCSDA).*

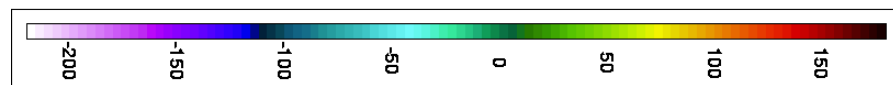
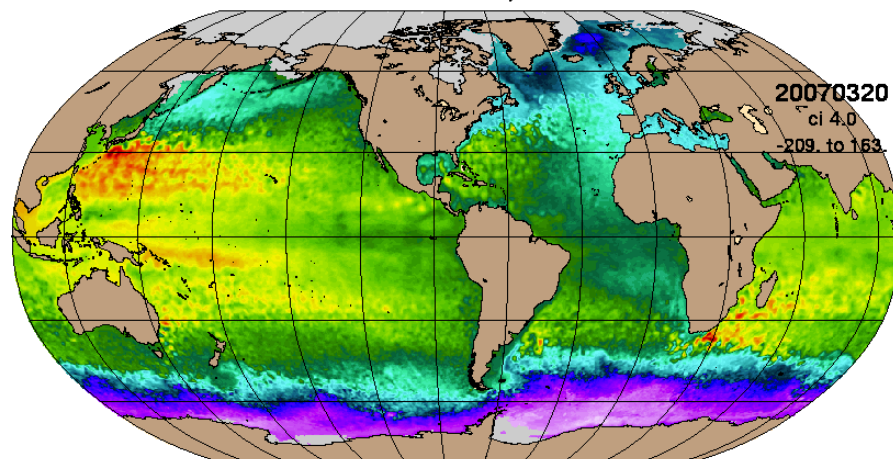


NRL Coupled Ocean Data Assimilation (NCODA)



Results from Real-Time .08° Global HYCOM

SSH date: Mar 23, 2007 90.2

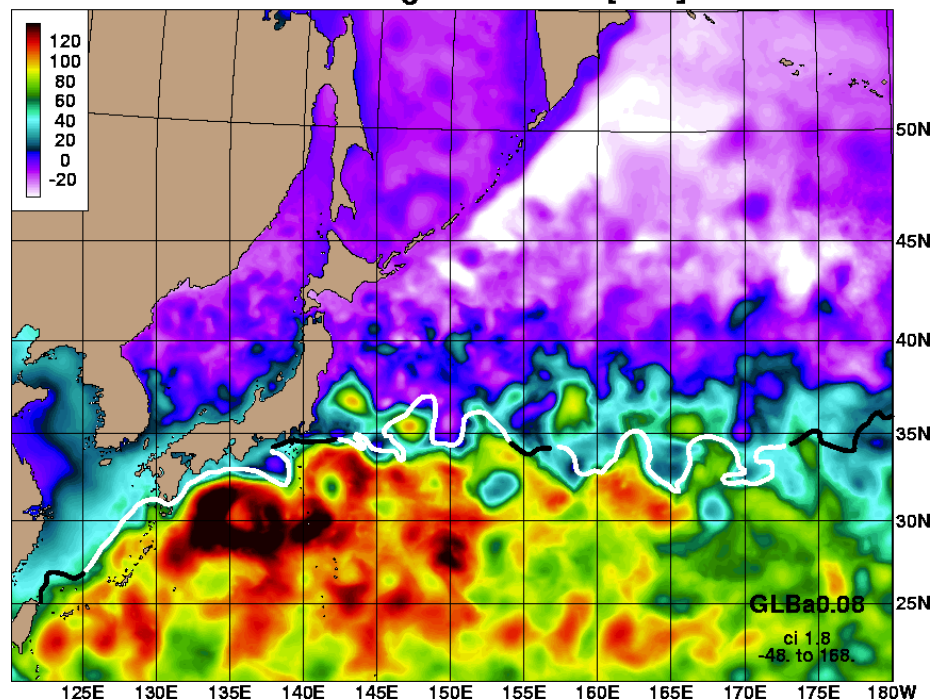


Sea Surface Height (SSH) in cm

Global SSH on 23 Mar 2007

Gray areas are ice covered

sea surf. height 20070312 [90.2]



NW Pacific SSH zoom on 12 Mar 2006

NAVOCEANO operational analysis of the Kuroshio front based on satellite AVHRR imagery is overlaid

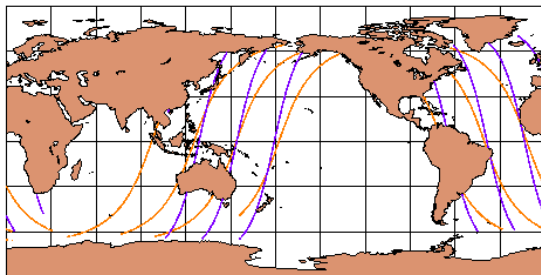
— black segments are based on imagery > 4 days old



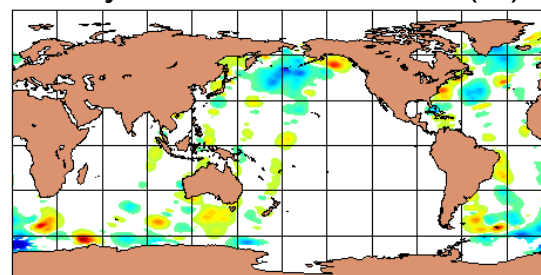
Wave Model Assimilation Validation

- Integrated wave model SWH assimilation and QC code in NCODA
- Completed QC of altimeter SWH data and free run of WW3 model as control
- Performing wave model assimilation runs for pre-beta validation
- Verification includes independent buoys and yet-to-be-assimilated altimeter data – SWH, mean wave period, and buoy spectra vs. model spectra

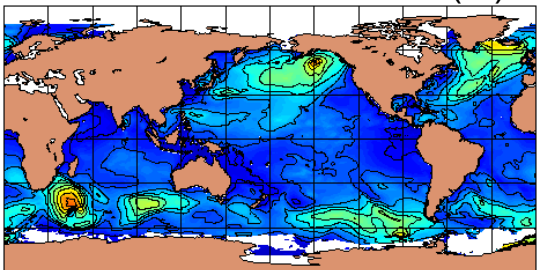
Altimeter SWH Observations



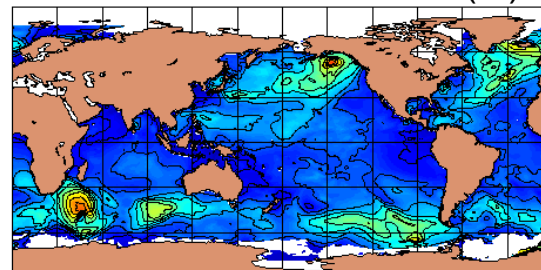
Analyzed Increment SWH (m)



Model Forecast SWH (m)



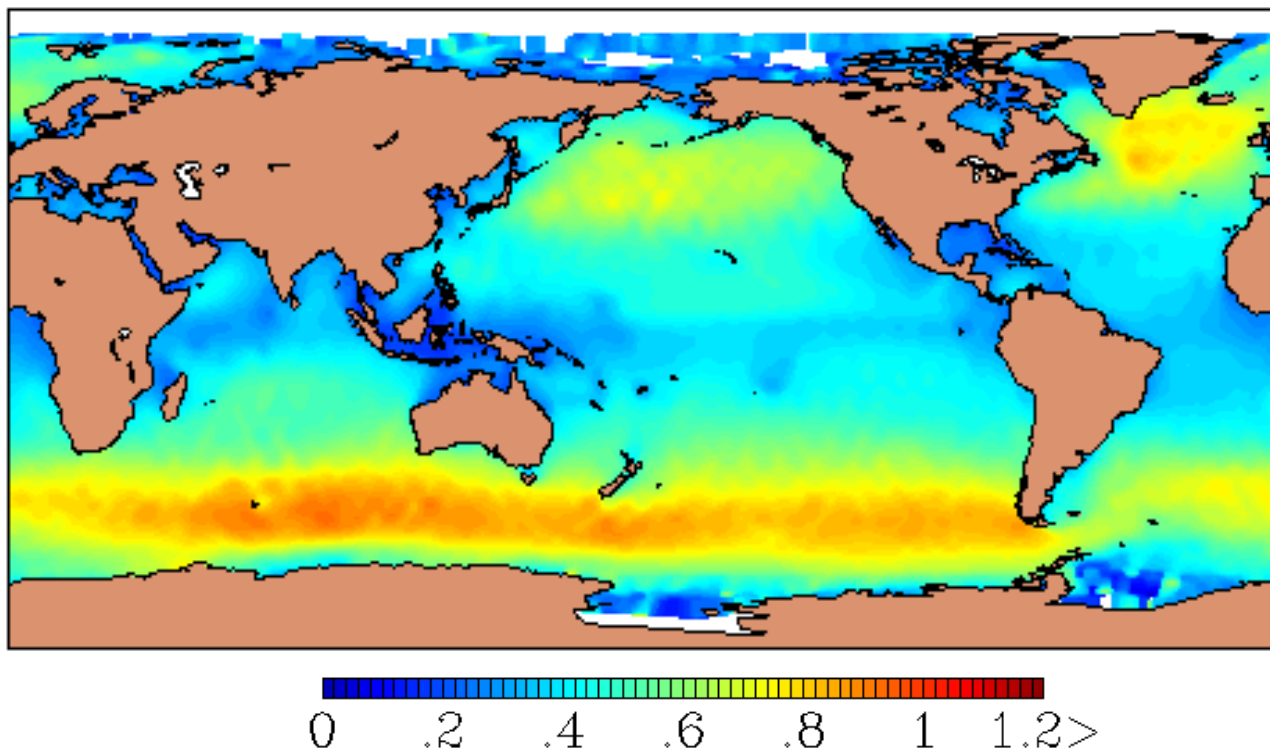
Corrected Model SWH (m)



Assimilation via 6-Hour Sequential Incremental Update Cycle



Wave Model Prediction Error



Altimeter SWH Prediction Error

SWH 6-hr prediction errors are highest in mid-latitudes and lowest in the tropics (computed from altimeter/model data match-ups from 2003 through 2006).



JCSDA UPCOMING EVENT

Executive Directors' Retreat



Hosted by NRL, June, 2007 in Monterey

- ✦ Discuss increased coordination between in-house activities of partner agencies.**
- ✦ Discuss what it means for an effort to be part of the JCSDA, given that there are multiple operational centers and multiple agencies operating outside the physical location of JCSDA.**
- ✦ Discuss JCSDA role in ocean data assimilation efforts of partner agencies.**
- ✦ Discuss sharing of software between partners and what limitations, if any, that implies.**



Satellite Data Assimilation Roadmap

| Sensor | Operational | Awaiting Transition to OPS | NRL Evaluation | Active Research | Future Work |
|---|-------------|----------------------------|----------------|-----------------|-------------|
| Geostationary winds (vis,IR,WV) SSM/I & SSMI/S TPW & wind speed AMSU-A radiances (NOGAPS) NESDIS ATOVS retrievals (COAMPS) MODIS AQUA & TERRA winds QuikSCAT & ERS/2 scatt. winds SSM/I & SSMI/S wind speed WindSat vector winds & TPW | | | | | |
| HIRS AMSU-B AQUA AIRS and AMSU SSMIS MW and IR Radiances over land AMSU-A radiances (COAMPS) | | | | | |
| MLS temp, water vapor, ozone CHAMP and COSMIC GPS METOP IASI, AMSU, MHS | | | | | |